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PROGRESS REPORT

NASA RESEARCH GRANT NGL 05-007-004

FOR THE PERIOD

JULY 1, 1971 - JUNE 30, 1972

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BACKGROUND INFORMATION

NASA research grant NGL 05-007-004 was awarded to the Institute of Geophysics and Planetary Physics of the University of California, Los Angeles, on March 1, 1962, in support of a space instrument development program. The participation of graduate students at the University is a basic part of the research effort.

The grant was renewed on July 1, 1963, with provision for a three-year step funding arrangement. Additional supplements were provided in July 1964, July 1965, October 1966, October 1967, October 1968, October 1969, October 1970, and October 1971.

The investigators whose work is supported under this grant, in the course of this work, have participated or are participating in the following projects: Mariners 2, 4, and 5 spacecraft; OV1-2 and OV1-12 satellites, both USAF; the ATS 1, OGO 5, and OGO 6 satellites; the Apollo 15 and 16 lunar subsatellites; and the Pioneer 10 project. They are participating in preparations for flight experiments for the ATS F and G satellites, and Pioneer (Jupiter) G. Fabrication of the flight hardware for these experiments is funded under separate contracts.

During the reporting period three new proposals were prepared by the investigators. The major portion of the proposal work was supported under this grant.

A. CHARGED PARTICLE RESEARCH

1. Experimental Studies

a. Electron Spectrometer for OGO-5

(PI supported in part with funds from this grant.) OGO-5 operations were terminated in October, 1971. Continuing studies are being made of various phenomena in cooperation with other experimenters on this spacecraft.

Work completed during the reporting period under a separate contract includes the completion of a paper on substorm particle observations which has been accepted for publication subject to revisions. A paper on boundary crossings in the nighttime magnetosphere has also been accepted for publication. A study of the effect of the orientation of the interplanetary magnetic field on the properties of polar cusp particles has been undertaken and the initial results have been reported at several meetings. Further work is in progress to test different models of the magnetosphere in the context of our observations.

Programs have been developed for the theoretical study of electron energization by electric fields in the tail. These programs await the imminent availability of a practical tail-field model for implementation. A survey of our data to identify "betatron acceleration" events has been initiated and a statistical study of these events is planned.

b. Electron Spectrometer for OGO-6

(PI supported in part with funds from this grant.) Under a separate contract a study of strong precipitation events, with emphasis on the ratio of precipitating to mirroring particles was

made and reported at the spring AGU meeting. A new finding is that this ratio significantly exceeds one in many precipitation events. A complete analysis for a written paper is underway.

2. Theoretical Studies

a. Radiation Belt Theoretical Studies

During the reporting period the study of inner zone electron population by inward radial diffusion during a geomagnetic storm has been accepted for publication and will appear in the Journal of Geophysical Research shortly.

A paper describing the effects of the secular change of the earth's dipole moment on the high energy protons of the inner zone has also been accepted for publication in the Journal of Geophysical Research.

Underway now is a paper collecting and describing all of the physical mechanisms known to affect the electrons and protons of the inner radiation zone.

B. MAGNETIC FIELDS RESEARCH

1. Introduction

The research activities discussed in this section are directed primarily toward the study of magnetohydrodynamic phenomena in the tenuous plasma above the ionosphere and in interplanetary space. A secondary goal is the direct measurement of the magnetic fields of planetary bodies. The work includes the development of the instruments with which to obtain such measurements and in some cases the reduction and analysis of data obtained with these instruments.

2. Instrument Development

During the reporting period magnetometer development studies, particularly studies of techniques of fabrication of ring core sensors, were continued.

A detailed study has been made of induction coil magnetometers. Special emphasis has been given to developing specifications for amplifiers to use with the induction coil systems. A search of state of the art integrated circuit amplifiers was made to determine if recently developed devices now available can meet these specifications.

3. Experimental Studies

a. ATS-1 Project

In Appendix B of our proposal, dated October 27, 1971, we described the proposed work to be carried out on the ATS-1 magnetometer project. This effort was divided into three major tasks: development of production data reduction programs; development of spectral analysis procedures; and scientific studies of stormtime Pc 5 waves, substorm-associated band-limited pulsations, and quiet time transverse Pc 4. In this report we give a brief summary of our progress in each of these areas.

Development of Production Data Reduction Programs

This phase of the proposed work was divided in two parts, automatic correction for spacecraft fields and new edit and demodulation programs. A new demodulation program was required to process all data acquired after November 2, 1969, when the ATS-1 sun sensor failed. Our initial work demonstrated the feasibility of using a solar cell interference signal on the magnetic sensor parallel to the spin axis as a pseudo sun sensor. It was shown however, that this signal depended on the spacecraft state. Furthermore, the spacecraft state could only be determined by making one complete pass through the data file. Since financial support for such processing was not provided for in this grant and since our request to NSF for such support was rejected, it was necessary to terminate work on this phase of the project.

A new edit program was also required to process all data acquired after June 30, 1970. On this date NASA ceased recording

and processing the environmental measurement data on ATS 1. Beginning in September, 1970, these data were again obtained by the National Oceanic and Atmospheric Administration (NOAA) at Boulder, Colorado. An edit program was required to interface the new tape format with existing programs. Since these data could not be processed with this new demodulation program, it was also necessary to terminate work on this project.

Our work on automatic correction of the ATS-1 magnetometer data for the years 1967-1968 is almost completed. As discussed in our previous proposals, there were a number of remaining problems with the effects of the spin scan cloud camera and VHF transmitter. Considerable effort was required to solve the latter problem. It was found that inaccuracy of the correction vectors was a result of a seasonal dependence of the spacecraft fields. Consequently, it was necessary to completely recalculate the correction vectors on a monthly, rather than a yearly basis.

The production costs for correcting the ATS-1 magnetometer data were not provided by this grant. As mentioned before, our proposal to NSF to finance this work was rejected. Fortunately, we were able to obtain an intramural grant from UCLA to carry out this work. The constraints of this grant obligated us to complete the work before July 1, 1972. Further, no money would be available for microfilm plotting.

In order to complete the correction procedure within these limits, we terminated our attempts to solve the spin scan cloud camera problems in the first pass through the data. Further, it

was necessary to develop a Cal-Comp program to plot the corrected output. (A Cal-Comp plotter is available without charge.) As discussed next, programming effort in spectral analysis was redirected to complete the correction procedures.

At the present time, the entire year of 1967 and part of 1968 have been automatically corrected. Data were produced at both 15 second and 2-1/2 minute time resolution. We are now in the process of plotting these data. A sample output of the plot program has been sent to the National Space Science Data Center. These plots will be photographed on microfilm and stored in the archives. In addition, BCD tapes of the corrected output are being generated and will also be submitted about July 30, 1972.

Development of Spectral Analysis Procedures

In our proposal we indicated our desire to develop spectral analysis procedures to handle data with noise and gaps. In addition, we planned to determine empirically errors in the analysis procedure by generating ensembles of test functions. In beginning this work we discovered a duplication of many of our previous programs. The reason for this was that in the past each project developed special programs starting with the particular form of data peculiar to the given project. Invariably the final programs were so specific as to require extensive modification before use in a new project.

To counter this tendency we adopted a modular approach in our data analysis. The basis of this system is a constant internal format in analysis called a "blocked data set" (BDS). The form

of this data set is sufficiently general to encompass all the input and output data types that we presently use. The requirement that all programs read these as input and write them as output insures that we will always be able to process data from any source. The additional requirement that analysis procedures be organized as a sequence of steps with each step utilizing BDS's further insures that new procedures can be quickly assembled from existing modules.

At the present time we have completed a number of essential steps in developing the modular approach. The first step was generating interface programs so each of our existing data sources could be converted to a BDS. Next, we wrote several conversion programs so that the BDS could be input to existing programs. We have begun writing a number of BDS utility programs, including a general print-punch program to output a BDS, a general Cal-Comp plot program for time series plots, and a general contour map program for functions of two variables. Presently under development are a general merge program and a general input-output routine. Also, we have completed the first analysis procedure utilizing only BDS's in a stepwise function.

Our experience to date with this new programming philosophy has been quite successful. We have greatly reduced the duplication of effort in which each programmer develops specialized display programs for his own use. Further, we find that the stepwise analysis procedure is very easy to change in response to new ideas.

Our eventual goal in these developments remains the same, i.e., improvement and calibration of our spectral analysis procedures. While we have delayed this goal somewhat, we believe we will be amply repaid by the generality of the routines we are developing.

Scientific Studies of ULF Waves at Synchronous Orbit

While we have been developing correction programs to remove spacecraft fields, our main scientific interest has been limited to fluctuating fields, particularly the area of ULF waves at synchronous orbit. Our existing program structure, embodying an earlier version of the blocked data set concept discussed above, has been adequate to carry out several studies. These include work on stormtime Pc 5 waves, substorm-associated band-limited Pi 1 pulsations, and quiet time transverse Pc 4 waves. In each of these studies we have obtained a number of interesting results.

Stormtime Pc 5 Micropulsations

Work on this part of the project was carried out by a Ph.D. candidate, J.N. Barfield, under the direction of Professor R.L. McPherron. Major experimental results of this work are summarized in the abstract of his dissertation, to be found in Section F.

Band-Limited Pi 1 Micropulsations

During magnetospheric substorms Pi 1 micropulsations are seen in the auroral zone during almost every substorm. These waves tend to be band-limited and associated with modulated electron precipitation and pulsating aurora. Despite these systematic correlations, almost nothing is known of the cause

of this phenomenon. A beginning graduate student, C. Arthur, has started a study of this problem under the direction of Professor R.L. McPherron. The initial results were presented at the April 1972 meeting of the American Geophysical Union (see Section F for abstract). A summary of these and additional results is presented below.

The first step in determining the properties of band-limited Pi 1 micropulsations at ATS 1 was to scan high-resolution microfilm plots of the data. Approximately 140 days of data were examined in this way. Data between 1000 UT and 1800 UT were scanned for waves of ~20 sec period. For many of the days scanned, however, data were not available during the hours of interest. On the basis of the criterion stated above, 15 potential events were selected for analysis. Seven other days, for which high resolution plots were not available, were also examined because correlative data were available. Initial spectral analysis indicated that only 9 of these 22 events were suitable for further study. Many of the other events showed evidence of the phenomenon being studied but contained an excess of interference in the data.

For the 9 events selected for further study, there were 20 hour-long intervals in which spectral lines were present. When the characteristics of these events were studied in a statistical manner, some patterns began to emerge.

The waves are significantly band-limited at 20-30 sec period, but not highly polarized (mean 70%), linear, transverse to magnetic field in the equatorial plane, azimuthally polarized, and

they have a local time occurrence pattern which peaks at 0800 LT. These characteristics agree fairly well with those obtained in our previous work.

Examination of sonograms and telluric current records published by the University of Alaska in High Latitude Geophysical Data showed that, for 8 of the 9 events, there was micropulsation activity on the ground at College similar to that observed at the satellite.

Because of the limited availability of overlapping Tungsten and ATS-1 data, only one event has been found for which an event was seen at both locations. The event at ATS 1 was very weak, and the spectral lines were not as well defined as those of the much clearer and stronger event at Tungsten. Dynamic spectra of the times in question reveal that there are several bursts at the frequency in question for which there is a rather weak correspondence in time of occurrence. This event does not present conclusive evidence as to whether the events seen at the two locations are, in fact, the same or different phenomena.

A Study of Quiet Time Transverse Pc 4 Micropulsations

As part of our support for other projects, we are cooperating with Professor W.D. Cummings of the Department of Physics, Grambling College, Grambling, Louisiana, in a study of Pc 4 micropulsations. Our contribution to this project has been to perform dynamic cross spectral analysis on approximately 20 wave events. Initial results of this statistical survey were presented at the April 1972 meeting of the American Geophysical Union. These results are summarized by

the abstract entitled "Spectral and Polarization Analysis of Micropulsations Observed at ATS 1" in Section F of this report.

b. Mariner Project

We have extended our studies of the radial dependences, i.e., dependences of distance from the sun, of the power spectra of the interplanetary magnetic field using measurements taken with the Mariner 4 and Mariner 5 magnetometers. New fast fourier transform power spectra programs were developed and separate analysis was done for data taken at active times and at quiet times in order to study the changes in the spectra with activity. The results of these analyses are being compared with theories for the production and damping of waves in the solar wind.

4. Theoretical Studies

a. Solar Wind Interaction with Interstellar Medium

Our analysis of the effect of the ionization of interstellar neutrals upon the spiral angle of the interplanetary magnetic field was extended. First, the model of neutral density was generalized to include gravitational focusing and temperature. The transfer of angular momentum to the newly ionized particles was calculated using these models. The resulting unwinding of the field was found to agree substantially with that reported earlier.

The two fluid equations were used in an extension of the theoretical treatment of the interaction. A generalized Ohm's law was formed including sources in the flow. The resulting relation was found to behave in a manner similar to a collision dominated ion-electron-neutral plasma.

The thermal energy equation for each of the two charged particle species was also developed. As a result, the ion temperature predicted for 5 AU was found to be considerably higher than that predicted by an adiabatic theory without interaction with interstellar particles. The electron temperature was found to be relatively unaffected by the interaction.

These two results, a higher ion temperature, and an unwinding of the interplanetary spiralled field should be observable with the forthcoming Pioneer missions to Jupiter, if the interstellar density is 0.1 cm^{-3} or greater.

b. Solar Wind Model Studies

During the reporting period we continued work on models of the solar wind which include magnetic and rotational effects. The previously reported first order expansion of the magnetohydrodynamic equations about the nonrotating Parker solution was extended to include the effects of latitudinal variations in temperature, density, and magnetic field at the coronal boundary. Solar wind flow properties, including the latitudinal flow velocity, and latitudinal component of the interplanetary magnetic field, have been calculated for selected variations in the coronal boundary conditions, such as a hot coronal equator or hot coronal pole. As a specific example, a dipole-like variation in the magnitude of the coronal magnetic field resulted in quantitative effects of magnetic channeling.

C. PROPOSALS

During the reporting period three new proposals were produced

by the group supported under this grant. The first proposal was to the Air Force Cambridge Research Laboratory for an investigation of geomagnetic activity. The second was for correlative studies of Apollo 15 and 16 subsatellite magnetometer data with Explorer 35 and lunar surface magnetometer data. The last was for participation in the definition phase for Planetary Explorer missions to Venus: the rationale for, and design of a suitable fluxgate magnetometer.

D. STUDENT PARTICIPATION

A basic purpose of our research is to make it possible for students to participate in scientific experiments within the rapidly developing field of space science. The following graduate students have participated in our programs during the period covered by this report.

1. Carlene Arthur, Department of Planetary and Space Science, is studying the physics of the magnetosphere.

2. Joseph Barfield, Department of Planetary and Space Science, focussed on the physics of the magnetosphere and the interplanetary medium. During the reporting period, Mr. Barfield completed his requirements for the Ph.D. in Planetary and Space Physics. His dissertation was entitled "Pc 5 Geomagnetic Micropulsations Observed at the Synchronous, Equatorial Satellite ATS 1 during Magnetic Storms Storms."

3. Mac C. Chapman, Department of Planetary and Space Science, is working on the strong precipitation data obtained from the electron spectrometer on OGO 6.

4. Donald Childers, Department of Physics, is studying the physics of the magnetosphere. He is working with data from OGO 5 and ATS 1.

5. Bryan Horning, Department of Planetary and Space Science, is studying the physics of the magnetosphere.

6. B. R. Lichtenstein, Department of Planetary and Space Science, is concentrating his efforts in the area of lunar magnetism and the interaction of the solar wind with the moon.

6. Lawrence Sharp, Department of Planetary and Space Science, is studying lunar magnetism and the interaction of the solar wind with the moon.

7. The work of Ray Walker, Department of Planetary and Space Science, involves the study of electrons in the magnetotail, using data from the electron spectrometer on OGO 5.

8. Edwin Winter, Department of Planetary and Space Science, is studying the interaction of the solar wind with planetary and cometary bodies and the termination of the solar wind.

All of the registered graduate students whose support is provided by these programs are employed as research assistants in classifications normally open to graduate students under long-established UCLA regulations. Their rates of pay are established by the Regents of the University. A considerable effort is made to assign research tasks which are of special interest to the student, but the tasks themselves are not necessarily related directly or indirectly to any dissertation research that the student may eventually perform.

E. PUBLICATIONS AND REPORTS

Papers resulting, wholly or in part, from the research supported under this grant are listed chronologically below. An asterisk denotes a paper completed since the last report.

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F. ABSTRACTS

Abstracts of papers and talks concerning results of the research performed, wholly or in part, under this grant are included in this section. These abstracts pertain to papers completed during the reporting period and to talks prepared during this period.

Pc 5 Geomagnetic Micropulsations Observed at the Synchronous, Equatorial Satellite ATS 1 during Magnetic Storms

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The results of a study of the characteristics of Pc 5 geomagnetic micropulsations observed at the synchronous, equatorial satellite ATS 1 are presented. Magnetic field data from the UCLA fluxgate magnetometer on board ATS 1 formed the basis for the study. The results of the study are used to establish that the stormtime Pc 5 micropulsations play an important role in the dynamics of the stormtime ring current, and in the processes responsible for the magnetospheric substorm.

A study of the stormtime Pc 5's observed at ATS 1 during 1967 clearly established that the micropulsations are associated with the main phase minimum of geomagnetic storms, and are confined to the afternoon sector. The observed Pc 5's had a mean frequency of 0.005 Hz and a mean amplitude of 10 gammas; a typical event lasted one hour. The observed oscillations were highly elliptical and the major axis of polarization was closely confined to the geomagnetic meridian plane. A study of ground magnetograms showed that the onset of Pc 5 activity at the satellite is clearly correlated with the onset of the expansion phase of magnetospheric substorms.

Detailed comparison of magnetic field data from College, Alaska, and from ATS 1 showed that stormtime Pc 5 oscillation events observed at the satellite were also observed on the ground near the northern conjugate point. The results of the comparison suggest there exists a close coupling between the Pc 5's in space and the ground micropulsations.

A comparison of the magnetic field and energetic particle fluxes during stormtime Pc 5 micropulsation events revealed simultaneous variations in the magnetic field and particles. Cross spectral analysis showed the particle and magnetic-field variations to be well correlated in phase. The energetic electrons oscillated in phase and the energetic protons out of phase with the magnetic field.

During a large fraction of the Pc 5 micropulsation events, coincident Pc 1-2 oscillations were observed. The Pc 1-2 oscillations were quasi-sinusoidal, with periods 5-20 seconds, and amplitudes 1-2 gammas. The Pc 1-2's were transverse and left-hand elliptically polarized with respect to the ambient magnetic field. The Pc 1-2 oscillations appear to be due to ion cyclotron resonance of Alfven waves with energetic protons.

Abstract of the dissertation, University of California, Los Angeles, 1972.

Fluctuating Magnetic Field in the Magnetosphere 1: ELF and VLF Fluctuations

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The study of Extremely-Low-Frequency (ELF) and Very-Low-Frequency (VLF) waves in space has been intensively pursued in the past decade. Search coil magnetometers, magnetic loop antennas, and electric dipole antennas have been carried on board many spacecraft. The measurements performed by these instruments have revealed a multitude of wave phenomena, whose study in turn is providing a wealth of information on the physics of the magnetospheric and ionospheric plasma. Two classes of wave phenomena are observed: whistlers and emissions. The observed whistler phenomena include: multiple hop ducted whistlers, ion-cutoff whistlers, ion cyclotron whistlers, subprotonospheric whistlers, magnetospherically reflected whistlers and walking trace whistlers.

The emissions observed at high altitudes near the magnetic equator differ in many respects from those observed at low altitudes near the ionosphere. At high altitudes, inside the plasmasphere ELF hiss is the dominant emission and outside the plasmasphere chorus is the dominant emission. Also seen is a sub-LHR hiss band in the outer plasmasphere near the equator, and high pass noise and broadband noise in the outer nightside magnetosphere. At low altitude both ELF hiss and chorus are present but, here, ELF hiss is the dominant emission even outside the plasmasphere. Additional emissions, specific to low altitudes, such as VLF hiss and LHR noise are also observed. Although the observations of these

phenomena by spacecraft have been complemented by many ground-based and rocket borne studies as well as by spacecraft observations of man-made signals, this paper reviews only satellite observations of signals of natural origin.

Space Science Reviews, 12, 810-856, 1972.

Fluctuating Magnetic Fields in the Magnetosphere
2. ULF Waves

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The study of ULF waves in space has been in progress for about 12 years. However, because of numerous observational difficulties the properties of the waves in this frequency band (10^{-3} to 1 Hz) are poorly known. These difficulties include the nature of satellite orbits, telemetry limitations on magnetometer frequency response and compromises between dynamic range and resolution. Despite the paucity of information, there is increasing recognition of the importance of these measurements in magnetospheric processes. A number of recent theoretical papers point out the roles such waves play in the dynamic behavior of radiation belt particles.

At the present time the existing satellite observations of ULF waves suggest that the level of geomagnetic activity controls the types of waves which occur within the magnetosphere. Consequently, we consider separately quiet times, times of magnetospheric substorms and times of magnetic storms. Within each of these categories there are distinctly different wave modes distinguished by their polarization: either transverse of parallel to the ambient field. In addition, these wave phenomena occur in distinct frequency bands. In terms of the standard nomenclature of ground micropulsation studies ULF wave types observed in the magnetosphere include quiet time transverse - Pc 1, Pc 3, Pc 4, Pc 5 quiet time compressional - Pc 1 and Pi 1; substorm compressional

Pi 1 and Pi 2; storm transverse - Pc 1; storm compressional Pc 4, 5. The satellite observations are not yet sufficient to determine whether the various bands identified in the ground data are equally appropriate in space.

Space Science Reviews, in press, 1972.

An Effect of the Ionization of Interstellar Particles on the Interplanetary Magnetic Field

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The flow of interstellar neutral particles into the interplanetary medium and their subsequent ionization in the presence of the electromagnetic field of the solar wind results in a transfer of momentum between that field and the newly ionized particles. Part of this transfer involves a loss of angular momentum from the solar wind electromagnetic field to these particles. One effect of this loss is an unwinding of the spiralled magnetic field of the solar wind. The magnitude of this effect is evaluated for specific models of neutral density and ion production. The effects of solar gravitation and light pressure are included. A neutral interstellar gas composed of 15 per cent helium and 85 per cent atomic hydrogen was assumed external to the solar system. For the case of an interstellar number density of 0.1 cm^{-3} and a velocity of 10 km sec^{-1} relative to the sun, the spiral angle reaches a maximum value of 70° at approximately 3 a.u. and then decreases with increasing distance from the sun to 45° (the value at 1 a.u.) at the orbit of Jupiter.

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Some Characteristics of Low-Frequency Oscillations Observed at ATS 1

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Low-frequency oscillations of the magnetic field at ATS 1 have been analyzed for the 25-month data interval December 1966 to December 1968. Irregular oscillations and oscillations associated with magnetic storms were excluded from the analysis. Of the 222 events identified, 170 events were oscillating predominantly transverse to the background magnetic field. The oscillations were observed to occur most frequently in the early afternoon hours. They also seemed to occur more frequently during December, January, and February than at other times of the year. During a given individual event the frequency was fairly constant and it varied between 1.5×10^{-3} and 20×10^{-3} Hz with a broad peak near 10×10^{-3} Hz. The event duration varied between a minimum of 10 min and a maximum of 14 hours and 26 min. During a given event the amplitude varied. The average maximum amplitude of an event was $\delta B \simeq 3\gamma$.

J. Geophys. Res., 77 (4), 748-750, 1972.

Storm-Associated Pc 5 Micropulsation Events Observed at the Synchronous Equatorial Orbit

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Quasi-sinusoidal magnetic-field oscillations (micropulsations) are regularly observed at ATS 1 during geomagnetic storms. The wave events typically occur during the main phase and tend to be confined to the afternoon sector. All observed events have been closely correlated with magnetospheric substorm activity. Power spectral analysis shows that the observed oscillations are composed of harmonically related components. Twenty-six wave events were observed in 1967; the analysis of three typical Pc 5 events is presented here. The observations are compared with the predictions of theory for a hot ($\beta \gtrsim 1$) inhomogeneous plasma. It is suggested that the observed micropulsations can be understood as the occurrence of either an Alfven wave instability, or a drift instability, of the enhanced storm-time ring current. However, it is concluded that the proposed models require further refinement for a definitive explanation of the observations.

J. Geophys. Res., 77 (1), 143-158, 1972.
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Magnetic Field Variations at ATS 1

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Magnetic field variations observed with the magnetometer on the ATS 1 satellite are briefly described. These variations are classified according to whether they are macroscopic field changes or fluctuations and also whether they occur during quiet, disturbed (substorms), or very disturbed (storms) times. It is concluded that a complete understanding of these complex, interrelated phenomena still requires much detailed study.

Published in The ESRO Geostationary Magnetospheric Satellite, ESRO Publ. No. SP-60 (Proc. ESRO Colloquium, Lyngby, Denmark, October, 1969), 1971.

Ground-Satellite Correlations of Substorm Pi 1 Micropulsations

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Ground observations indicate that Pi 1, which occur predawn during magnetospheric substorms, have a strong band-limited component. Spectra from events detected with the UCLA magnetometer at Tungsten, Canada, are used to determine whether this component is characteristic of Pi 1 or the result of superimposed Pc 3. Since it has been suggested that Pi 1 has a magnetospheric origin, satellite magnetometer data that resemble Pi 1 at the surface assume importance. Indeed, one band-limited Pi 1 event has apparently been observed both on the ground and in space. Previously unreported Pi 1 events from ATS 1 exhibit a strong sinuosidal component and rarely occur before dawn. This occurrence pattern suggests a spatially localized region of wave generation which is consistent with the postulated origin. (OGO 5 data are used to establish the radial localization of wave occurrence.) In addition to the satellite data, electron precipitation also suggests a magnetospheric origin. Balloon data during ATS 1 events sometimes show a correspondence between the wave period and the period of modulation of precipitation.

Presented at the Spring Meeting of the American Geophysical Union, Washington, D.C., April, 1972.

Fourier Analysis of the Substorm Depression and Expansion Phases

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The change in the horizontal component of the magnetic field measured at ATS 1 and 14 mid latitude ground stations is investigated for 47 moderately sized substorms. A Fourier analysis of the deviation of the horizontal component from the quiet day shows a strong first harmonic component with the minimum in the first harmonic located at roughly 1800 LT for most events as reported earlier by Crooker and Siscoe. Higher harmonics became important at the onset of the expansion phase suggesting that the substorm expansion is not simply the result of turning off the partial ring current, but of the growth and motion of a separate current system. Contour plots of local time versus universal time with the horizontal component as the contoured parameters are presented illustrating these results.

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Frequency Dependence of ATS-1 Observed Micropulsations on Some Geophysical Parameters

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Low frequency oscillations in the earth's magnetic field at the synchronous orbit have been observed with the UCLA magnetometer experiment on board the ATS-1 satellite since Dec. 1966. Some general characteristics of oscillations in the range $2\times10^{-3} < f < 20\times10^{-3}$ Hz have been previously reported by these authors. A further analysis of oscillations in the above mentioned range for the two year interval Dec. 1966 through Dec. 1968 is reported here. It was found that the frequency of an event increases with the sum of Kp for 24 hours prior to the event midpoint. For events with duration greater than 6 hours, the product moment correlation coefficient for frequency, f, and ΣKp was R=0.853. The best least squares linear fit to the data for these events was $f=(0.34)\ \Sigma Kp + 4.81$. For the same events the correlation coefficient for frequency and D_{st} was R = -0.676.

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Spectral and Polarization Analysis of Micropulsations Observed at ATS-1

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This paper reports the results of an analysis of low-frequency oscillations in the earth's magnetic field as observed at the synchronous orbit by the UCLA magnetometer experiment on board ATS-1. Oscillations in the range $2 \times 10^{-3} < f < 20 \times 10^{-3}$ Hz for the two year period Dec. 1966 through Dec. 1968 were studied. The analysis combines a detailed, computer processed, spectral analysis of selected events with a less detailed manual analysis of all events in the two year time interval. The computer analysis revealed that a given event is often characterized by a dominant, narrow, spectral peak whose associated oscillations are almost entirely limited to a plane, together with several minor peaks. Dynamic spectral analyses reveal that the minor spectral peaks appear as short isolated bursts. In the manual analysis microfilm records of all events were used to determine the sense of polarization as a function of local time, frequency, and Kp.

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Simultaneous Observations of Correlated Storm Associated ULF Magnetic Oscillations at ATS 1 and College, Alaska

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Detailed analysis indicates that a meridional oscillation event observed at the synchronous equatorial satellite ATS 1 during the main phase of a geomagnetic storm was also observed on the ground near the northern conjugate point. Data from the UCLA flux-gate magnetometer on ATS 1 were compared with digitized data from an induction coil magnetometer at College, Alaska. The similarity of the wave forms and auto spectra at the two locations suggests that there exists a close coupling between the low frequency waves in space and the ground micropulsations.

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Propagation of ULF Waves (Micropulsations) along Field Lines and Through the Auroral Ionosphere

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Previous work attempting to determine the transfer function of the ionosphere has shown it is difficult to determine either theoretically or experimentally. One of the major problems in the experimental work has been lack of information about the input signal from the magnetosphere. In this paper we report results of an experimental study in which the "input" has been measured with the UCLA fluxgate magnetometers on the synchronous satellite ATS 1 and the eccentric satellite OGO 5. Simultaneous ground measurements of the "output" have been made with magnetometers near the ATS 1 conjugate point. An examination of Pc 1 micropulsations (5 second period) shows that field line geometry is very important in studying waves which are collimated along field lines. Variation of signal amplitude across a flux tube in the magnetosphere or wave propagation in the ionospheric duct seriously hamper the measurement of ionospheric effects. A study of band limited Pi 1 micropulsations (25 second period) has revealed that the waves are quite rare at synchronous orbit in comparison with the very frequency occurrence at the calculated conjugate point during substorms. An attempt will be made to see if the waves are localized at specific radial distances in the magnetosphere, using the eccentric satellite OGO 5. A study of stormtime Pc 5 micropulsations (200 second period) shows the waves are simultaneously present at the ground and synchronous orbit with similar properties.

Previous reports that Pc 5 do not occur on the ground during storms were apparently wrong, due to the subjective analysis techniques used. These initial results show that the measurement of the ionospheric transfer function is more difficult than expected and requires future improvements in both data acquisition and analysis. Such an improvement using a synchronous satellite as a receiving station from an array of remote observatories will be briefly described.

Presented at Navy Long Radio Wave Propagation Symposium Naval Research Laboratory, April 25-27, 1972, Washington, D.C.

Effects of the Interstellar Particles Upon the Interaction of Cosmic Rays With the Interplanetary Magnetic Field

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The flow of interstellar neutral particles into the interplanetary medium has been established observationally. We have suggested that the ionization of these particles will result in an unwinding of the spiral magnetic field. This effect, caused by a transfer of angular momentum from the solar wind electromagnetic field to these newly ionized particles, is evaluated for cases in which the interstellar gas density is less than or equal to one atom cm^{-3}. We suggest that this unwinding can account for the boundary effect at 3-5 AU indicated by cosmic ray modulation even if the termination of the solar wind occurs at distances greater than 60 AU.

Presented at the 12th International Conference on Cosmic Rays, Hobart, August, 1971.

Effects of the Secular Decrease of the Earth's Dipole Moment on High Energy Trapped Protons

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Schulz and Paulikas have suggested that the azimuthal electric field resulting from the slow decrease of the earth's magnetic moment will cause significant inward convection and acceleration of high energy protons which are trapped for centuries in the inner radiation zone. We have confirmed this suggestion by incorporating these additional effects in a earlier model which predicts the particle distribution function resulting from albedo neutron decay, radial diffusion, and atmospheric collision loss. Modest but significant increases in the distribution function, particularly at low L values (<1.3) are apparent. The addition of these effects improves the agreement between the model and the experimental data. No attempt has been made to include the effects of the secular change of the higher multipole terms, whose long term variation is not well known.

Presented at the Fall Meeting of the American Geophysical Union, San Francisco, Calif., December, 1971.

Ground-Satellite Correlations for Substorm Wave Phenomena

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A magnetic observatory measuring the DC magnetic field and its fluctuations has been established at the ATS-1 conjugate point at Tungsten, N.W.T., Canada. On October 10, 1969, a sequence of substorms occurred as the meridian of the satellite rotated through the night hemisphere. Four distinct types of wave phenomena were observed on the ground associated with the different substorms. These include IPDP at dusk, Pi 2 bursts and irregular pulsations at midnight and band limited pulsations in the morning sector. Each of these wave phenomena has been observed at the satellite though not all on this night. The properties of these waves in space and their relation to the ground observations will be discussed.

Presented at the Fall Annual Meeting of the American Geophysical Union, San Francisco, Calif., December, 1971.

An Interaction Between the Solar Wind Electromagnetic Field and Interstellar Particles

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The currents associated with the acceleration of interstellar particles upon their ionization in the solar wind can cause a decrease in the spiral angle of the interplanetary field. These currents are in the direction of the interplanetary electric field and result in a negative gradient of $|B_\phi r|$ with distance from the sun. The magnitude of this effect is evaluated for various models of neutral density incorporating solar gravitation and finite gas temperature. For an interstellar neutral density suggested by observations, $\sim.2$ cm^{-3}, this effect can cause an unwinding of the spiral to less than 45° before the orbit of Jupiter. The degree of this unwinding is calculated for various azimuthal angles in the ecliptic plane. The unwinding can be detected with the forthcoming Pioneer probes to Jupiter. While this effect is maximum in the direction of interstellar inflow, some unwinding will occur for all angles.

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A Modular Approach to the Digital Analysis of Vector Time Series

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The study of such phenomena as low frequency electromagnetic waves benefits greatly from the conveniences of digital data, and the corresponding variety of computer analysis techniques available. However, many of these techniques have proven difficult to utilize, due to long delays in reprogramming for changes in data format or analysis. We have attempted to overcome such difficulties by a modular approach to time series analysis. We utilize the modular structure of Fortran programming, with subroutines for desired operations, and we require all data to have a standard format. To interface with actual input data we use a library of conversion routines. All programs are stored in the direct access memory of an IBM 360-91. Program access is facilitated by the data set manipulation of the computer, with interaction via remote television console. The structure and use of this modular approach will be demonstrated by outlining the analysis of low frequency electromagnetic waves which occurred simultaneously at ATS 1 and Tungsten, N.W.T., Canada.

Presented at the Fall Annual Meeting of the American Geophysical Union, San Francisco, Calif., December, 1971.

Correlations Between Magnetic Field Changes at ATS 1 and Low Latitude Ground Stations

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The horizontal component of the magnetic field at the synchronous satellite ATS 1 and at several low latitude ground stations was studied during weak and moderate substorms which occurred in December 1966 and early 1967. The field at ATS was found to correlate closely with the ground field measurements through the expansion phase though not consistently through the growth phase of these substorms. A fit of these data to a field aligned current model suggests that the changes during the expansion phase are caused by several different current systems. A method of locating these currents using both satellite and ground data is suggested and the approximate position of these currents is found for the data.

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The Semiannual Variation in Geomagnetic Activity

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It has been established in many studies that the southward component of the interplanetary magnetic field is the primary agent in transfer of solar wind energy from the solar wind into the magnetotail. Substorms then release this energy into the magnetosphere and cause the various phenomena classed as geomagnetic activity. The fact that the interplanetary field is ordered in solar equatorial coordinates while the interaction is controlled in solar magnetospheric coordinates plus the fact that the magnetosphere acts as a rectifier leads to a very simple explanation of the semiannual variation of geomagnetic activity. The diurnal and annual variation predicted by this and other models will be compared.

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